

Amendments to the Claims:

This listing of claims will replace all prior versions, and listings, of claims in the application:

Listing of Claims:

- 1           1.     (Currently Amended) A linear method for performing head  
2     motion estimation from facial feature data, the method comprising  
3     the steps of:  
4             obtaining a first facial image and detecting a head in said  
5     first image;  
6             detecting position of ~~not more than only~~ four points  $P$  of said  
7     first facial image where  $P = \{p_1, p_2, p_3, p_4\}$ , and  $p_k = (x_k, y_k)$ ;  
8             obtaining a second facial image and detecting a head in said  
9     second image;  
10            detecting position of ~~not more than only~~ four points  $P'$  of  
11     said ~~first~~ second facial image where  $P' = \{p'_1, p'_2, p'_3, p'_4\}$  and  $p'_k = (x'_k, y'_k)$ ;  
12     and  
13            determining the motion of the head represented by a rotation  
14     matrix  $R$  and translation vector  $T$  using said points  $P$  and  $P'$ .

1           2.     (Currently Amended) The linear method of claim 1, wherein  
2 | said only four points  $P$  of said first facial image and said only  
3 four points  $P'$  of said second facial image include locations of  
4 outer corners of each eye and mouth of each respective first and  
5 second facial images.

1           3.     (Original)       The linear method of claim 1, wherein said  
2 head motion estimation is governed according to:

3            $P'_i = RP_i + T$ , where  $R = \begin{bmatrix} r_1^T \\ r_2^T \\ r_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$  and  $T = [T_1 \ T_2 \ T_3]^T$  represent camera  
4 rotation and translation respectively, said head pose estimation  
5 being a specific instance of head motion estimation.

1           4.     (Currently amended) A linear method for performing head  
2 motion estimation from facial feature data, the method comprising  
3 the steps of:

4           obtaining a first facial image and detecting a head in said  
5 first image;

6           detecting position of four points  $P$  of said first facial image  
7 where  $P = \{p_1, p_2, p_3, p_4\}$ , and  $p_k = (x_k, y_k)$ ;

8           obtaining a second facial image and detecting a head in said  
9 second image;

10 | detecting position of four points  $P'$  of said ~~first-second~~

11 facial image where  $P' = \{p'_1, p'_2, p'_3, p'_4\}$  and  $p'_k = (x'_k, y'_k)$ ; and,

12 determining the motion of the head represented by a rotation

13 matrix  $R$  and translation vector  $T$  using said points  $P$  and  $P'$ ,

14 wherein said head motion estimation is governed according to:

15  $P'_i = RP_i + T$ , where  $R = \begin{bmatrix} r_1^T \\ r_2^T \\ r_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$  and  $T = [T_1 \ T_2 \ T_3]^T$  represent camera

16 rotation and translation respectively, said head pose estimation

17 being a specific instance of head motion estimation, and

18 wherein said head motion estimation is governed according to

19 said rotation matrix  $R$ , said method further comprising the steps

20 of:

21 determining rotation matrix  $R$  that maps points  $P_k$  to  $F_k$  for

22 characterizing a head pose, said points  $F_1, F_2, F_3, F_4$  representing three-

23 dimensional (3-D) coordinates of the respective four points of a

24 reference, frontal view of said facial image, and  $P_k$  is the three-

25 dimensional (3-D) coordinates of an arbitrary point where

26  $P_i = [X_i \ Y_i \ Z_i]^T$ , said mapping governed according to the relation:

27

$$R(P_2 - P_1) \propto [1 \ 0 \ 0]^T$$

28

$$R(P_6 - P_5) \propto [0 \ 1 \ 0]^T$$

29

30 wherein  $P_5$  and  $P_6$  are midpoints of respective line segments  
 31 connecting points  $P_1P_2$  and  $P_3P_4$  and, line segment connecting points  
 32  $P_1P_2$  is orthogonal to a line segment connecting points  $P_5P_6$ , and  
 33  $\propto$  indicates a proportionality factor.

1 5. (Original) The linear method of claim 4, wherein  
 2 components  $r_1$ ,  $r_2$  and  $r_3$  are computed as:

$$\begin{aligned} & r_2^T (P_2 - P_1) = 0 \\ & r_3^T (P_2 - P_1) = 0 \\ 3 \quad & r_1^T (P_6 - P_5) = 0 \\ & r_3^T (P_6 - P_5) = 0 \end{aligned}$$

1 6. (Original) The linear method of claim 5, wherein  
 2 components  $r_1$ ,  $r_2$  and  $r_3$  are computed as:

$$\begin{aligned} 3 \quad & r_3 = (P_6 - P_5) \times (P_2 - P_1), \\ & r_2 = r_3 \times (P_2 - P_1) \\ 4 \quad & r_1 = r_2 \times r_3 \end{aligned}$$

1 7. (Original) The linear method of claim 4, wherein

$$\begin{bmatrix} P_1^T & 0^T & 0^T & 1 & 0 & 0 \\ 0^T & P_1^T & 0^T & 0 & 1 & 0 \\ 0^T & 0^T & P_1^T & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ T \end{bmatrix} = P_1^T$$

2 ,

3       each point pair yielding 3 equations, whereby at least four  
4       point pairs are necessary to linearly solve for said rotation and  
5       translation.

1       8.     (Original)       The linear method of claim 7, further  
2       comprising the step of: decomposing said rotation matrix  $R$  using  
3       Singular Value Decomposition (SVD) to obtain a form  $R = USV^T$ .

1       9.     (Original)       The linear method of claim 7, further  
2       comprising the step of computing a new rotation matrix according to  
3        $R = UV^T$ .

1       10.    (Original)       A linear method for performing head motion  
2       estimation from facial feature data, the method comprising the  
3       steps of:  
4       obtaining image position of four points  $P_k$  of a facial image;  
5       determining a rotation matrix  $R$  that maps points  $P_k$  to  $F_k$  for  
6       characterizing a head pose, said points  $F_1, F_2, F_3, F_4$  representing  
7       three-dimensional (3-D) coordinates of the respective four points  
8       of a reference, frontal view of said facial image, and  $P_k$  is the

9 three-dimensional (3-D) coordinates of an arbitrary point where

10  $P_i = [X_i \ Y_i \ Z_i]^T$ , said mapping governed according to the relation:

11

$$R(P_2 - P_1) \propto [1 \ 0 \ 0]^T$$

12

$$R(P_6 - P_5) \propto [0 \ 1 \ 0]^T$$

13

14 wherein  $P_5$  and  $P_6$  are midpoints of respective line segments  
 15 connecting points  $P_1P_2$  and  $P_3P_4$  and, line segment connecting points  
 16  $P_1P_2$  is orthogonal to a line segment connecting points  $P_5P_6$ , and  
 17  $\propto$  indicates a proportionality factor.

1 11. (Original) The linear method of claim 10, wherein  
 2 components  $r_1$ ,  $r_2$  and  $r_3$  are computed as:

$$r_2^T(P_2 - P_1) = 0$$

$$r_3^T(P_2 - P_1) = 0$$

$$r_1^T(P_6 - P_5) = 0$$

$$r_3^T(P_6 - P_5) = 0$$

1 12. (Original) The linear method of claim 11, wherein  
 2 components  $r_1$ ,  $r_2$  and  $r_3$  are computed as:

$$r_3 = (P_6 - P_5) \times (P_2 - P_1),$$

$$r_2 = r_3 \times (P_2 - P_1)$$

$$r_1 = r_2 \times r_3$$

1           13. (Original)       The linear method of claim 12, wherein a  
2 motion of head points is represented according to  $P'_i = RP_i + T$

$$R = \begin{bmatrix} r_1^T \\ r_2^T \\ r_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$$

3           where  $R$  represents image rotation,  $T = [T_1 \ T_2 \ T_3]^T$   
4 represents translation, and  $P'_i$  denotes a 3-D image position of four  
5 points  $P_k$  of another facial image

1           14. (Original)       The linear method of claim 13, wherein

$$2 \quad \begin{bmatrix} P_i^T & 0^T & 0^T & 1 & 0 & 0 \\ 0^T & P_i^T & 0^T & 0 & 1 & 0 \\ 0^T & 0^T & P_i^T & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ T \end{bmatrix} = P'_i,$$

3           each point pair yielding 3 equations, whereby at least four  
4 point pairs are necessary to linearly solve for said rotation and  
5 translation.

1           15. (Original)       The linear method of claim 14, further  
2 comprising the step of: decomposing said rotation matrix  $R$  using  
3 Singular Value Decomposition (SVD) to obtain a form  $R = USV^T$ .

1           16. (Original)       The linear method of claim 15, further  
2 comprising the step of computing a new rotation matrix according to  
3  $R = UV^T$ .

1           17. (Currently Amended) A program storage device readable by  
2 machine, tangible embodying a program of instructions executable by  
3 the machine to perform method steps for performing head motion  
4 estimation from facial feature data, the method comprising the  
5 steps of:  
6           obtaining a first facial image and detecting a head in said  
7 first image;  
8           detecting position of ~~not more than~~ only four points P of said  
9 first facial image where  $P = \{p_1, p_2, p_3, p_4\}$ , and  $p_k = (x_k, y_k)$ ;  
10          obtaining a second facial image and detecting a head in said  
11 second image;  
12          detecting position of ~~not more than~~ only four points P' of  
13 said ~~first~~ second facial image where  $P' = \{p'_1, p'_2, p'_3, p'_4\}$  and  $p'_k = (x'_k, y'_k)$ ;  
14 and,  
15          determining the motion of the head represented by a rotation  
16 matrix R and translation vector T using said points P and P'.



1        18. (Currently amended) The program storage device readable  
2 | by machine as claimed in claim 17, wherein said only four points P  
3 | of said first facial image and only four points P' of said second  
4 | facial image include locations of outer corners of each eye and  
5 | mouth of each respective first and second facial image.

1        19. (Original)        The program storage device readable by  
2 machine as claimed in claim 17, wherein said head motion estimation  
3 is governed according to:

4         $P'_i = RP_i + T$ ,        where  $R = \begin{bmatrix} r_1^T \\ r_2^T \\ r_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$         and  $T = [T_1 \ T_2 \ T_3]^T$  represent  
5 camera rotation and translation respectively, said head pose  
6 estimation being a specific instance of head motion estimation.

1        20. (Previously presented)        A program storage device  
2 readable by machine, tangible embodying a program of instructions  
3 executable by the machine to perform method steps for performing  
4 head motion estimation from facial feature data, the method  
5 comprising the steps of:  
6        obtaining a first facial image and detecting a head in said  
7 first image;

8 detecting position of four points  $P$  of said first facial image  
 9 where  $P = \{P_1, P_2, P_3, P_4\}$ , and  $P_k = (x_k, y_k)$ ;  
 10 obtaining a second facial image and detecting a head in said  
 11 second image;  
 12 detecting position of four points  $P'$  of said ~~first~~second  
 13 facial image where  $P' = \{P'_1, P'_2, P'_3, P'_4\}$  and  $P'_k = (x'_k, y'_k)$ ; and  
 14 determining the motion of the head represented by a rotation  
 15 matrix  $R$  and translation vector  $T$  using said points  $P$  and  $P'$ ,  
 16 wherein said head motion estimation is governed according to:

$$R = \begin{bmatrix} r_1^T \\ r_2^T \\ r_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$$

17  $P'_i = RP_i + T$ , where and  $T = [T_1 \ T_2 \ T_3]^T$  represent  
 18 camera rotation and translation respectively, said head pose  
 19 estimation being a specific instance of head motion estimation, and  
 20 wherein said head pose estimation is governed according to  
 21 said rotation matrix  $R$ , said method further comprising the steps  
 22 of:

23 determining rotation matrix  $R$  that maps points  $P_k$  to  $F_k$  for  
 24 characterizing a head pose, said points  $F_1, F_2, F_3, F_4$  representing three-  
 25 dimensional (3-D) coordinates of the respective four points of a  
 26 reference, frontal view of said facial image, and  $P_k$  is the three-

27 dimensional (3-D) coordinates of an arbitrary point where  
28  $P_i = [X_i \ Y_i \ Z_i]^T$ , said mapping governed according to the relation:

29

$$\begin{aligned} R(P_2 - P_1) &\propto [1 \ 0 \ 0]^T \\ R(P_6 - P_5) &\propto [0 \ 1 \ 0]^T \end{aligned}$$

30

31

32 wherein  $P_5$  and  $P_6$  are midpoints of respective line segments  
33 connecting points  $P_1P_2$  and  $P_3P_4$  and, line segment connecting points  
34  $P_1P_2$  is orthogonal to a line segment connecting points  $P_5P_6$ , and  
35  $\propto$  indicates a proportionality factor.

1 21. (Previously presented) The program storage device  
2 readable by machine as claimed in claim 20, wherein components  $r_1$ ,  
3  $r_2$  and  $r_3$  are computed as:

$$\begin{aligned} r_2^T(P_2 - P_1) &= 0 \\ r_3^T(P_2 - P_1) &= 0 \\ r_1^T(P_6 - P_5) &= 0 \\ 4 \quad r_3^T(P_6 - P_5) &= 0 \end{aligned}$$

1 22. (Previously presented) The program storage device  
2 readable by machine as claimed in claim 20, wherein components  $r_1$ ,  
3  $r_2$  and  $r_3$  are computed as:

$$r_3 = (P_6 - P_5) \times (P_2 - P_1),$$

$$r_2 = r_3 \times (P_2 - P_1)$$

$$r_1 = r_2 \times r_3$$

23. (Previously presented) The program storage device  
readable by machine as claimed in claim 20, wherein

$$\begin{bmatrix} P_i^T & 0^T & 0^T & 1 & 0 & 0 \\ 0^T & P_i^T & 0^T & 0 & 1 & 0 \\ 0^T & 0^T & P_i^T & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ T \end{bmatrix} = P_i'$$

each point pair yielding 3 equations, whereby at least four  
point pairs are necessary to linearly solve for said rotation and  
translation.

24. (Previously presented) The program storage device  
readable by machine as claimed in claim 23, further comprising the  
steps of decomposing said rotation matrix R using Singular Value  
Decomposition (SVD) to obtain a form  $R = USV^T$ .

25. (Previously presented) The program storage device  
readable by machine as claimed in claim 23, further comprising the  
steps of computing a new rotation matrix according to  $R = UV^T$ .